

WHAT IS CLAIMED IS:

1. A semiconductor device comprising:

a gate insulating film formed on a substrate; and

5 a gate electrode formed on the gate insulating film;

the gate insulating film comprising:

a high dielectric constant film containing a metal, oxygen and silicon; and

a lower barrier film formed below the high dielectric constant film and containing the metal, oxygen, silicon and nitrogen.

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2. The semiconductor device according to claim 1, wherein

the gate insulating film comprises an upper barrier film formed above the high dielectric constant film, and

the upper barrier film contains the metal, oxygen and nitrogen.

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3. The semiconductor device according to claim 1, wherein

$$0.23 \leq y/(x+y) \leq 0.90$$

when a composition of the high dielectric constant film is expressed as M_xSi_yO , where M, O and Si represent the metal, oxygen and silicon, respectively, and $x > 0$ and $y > 0$.

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4. The semiconductor device according to claim 1, wherein

$$0.23 \leq y/(x+y) \leq 0.30$$

when a composition of the high dielectric constant film is expressed as M_xSi_yO , where M, O and Si represent the metal, oxygen and silicon, respectively, and $x > 0$ and $y > 0$.

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5. The semiconductor device according to claim 1, wherein

$$x/(x+y) \geq 0.10$$

when the metal is hafnium or zirconium, and

a composition of the lower barrier film is expressed as M_xSi_yON , where M, O, Si and N represent the metal, oxygen, silicon and nitrogen, respectively, and $x > 0$ and $y > 0$.

5 6. The semiconductor device according to claim 1, wherein the gate electrode is a metal gate electrode.

7. A method for producing a semiconductor device comprising the steps of:

forming a high dielectric constant film containing a metal, oxygen and a
10 predetermine substance on a substrate;

performing a heat treatment with respect to the high dielectric constant film to diffuse silicon from the side of the substrate into the high dielectric constant film, thereby forming a silicon-containing high dielectric constant film; and

forming a conductive film for serving as a gate electrode on the silicon-containing
15 high dielectric constant film.

8. The method for producing a semiconductor device according to claim 7, wherein the predetermined substance is hydrogen.

20 9. The method for producing a semiconductor device according to claim 7, wherein the metal is hafnium or zirconium.

10. The method for producing a semiconductor device according to claim 7, comprising forming an insulating film containing silicon, nitrogen and the predetermined substance on
25 the substrate before the step of forming the high dielectric constant film; and

wherein the step of performing a heat treatment with respect to the high dielectric constant film comprises diffusing silicon contained in the insulating film into the high

dielectric constant film, and forming a lower barrier film by diffusing the metal contained in the high dielectric constant film into the insulating film.

11. The method for producing a semiconductor device according to claim 7, wherein

5 the step of forming the high dielectric constant film comprises forming the high dielectric constant film by CVD employing a source precursor containing the metal and the predetermined substance.

12. The method for producing a semiconductor device according to claim 7, wherein

10 the step of forming the high dielectric constant film comprises forming the high dielectric constant film by CVD employing a source precursor containing the metal and a source gas containing the predetermined substance.

13. The method for producing a semiconductor device according to claim 7, wherein

15 the step of forming the high dielectric constant film comprises forming the high dielectric constant film by PVD employing a target containing the metal in an atmosphere containing the predetermined substance.

14. The method for producing a semiconductor device according to claim 7, comprising

20 the step of forming an upper barrier by nitriding a surface of the silicon-containing high dielectric constant film between the step of performing a heat treatment with respect to the high dielectric constant film and the step of forming a conductive film.

15. The method for producing a semiconductor device according to claim 7, comprising

25 the step of forming an upper barrier by nitriding a surface of the high dielectric constant film between the step of forming a high dielectric constant film and the step of performing a heat treatment with respect to the high dielectric constant film.

16. The method for producing a semiconductor device according to claim 7, wherein
a temperature for the heat treatment in the step of performing the heat treatment
with respect to the high dielectric constant film is 600°C or more and 850°C or less.

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17. The method for producing a semiconductor device according to claim 7, wherein

$$T \leq 6.69 \cdot y/(x+y) + 749.4,$$

when a composition of the silicon-containing high dielectric constant film is
expressed as M_xSi_yO , where M, O and Si represent the metal, oxygen and silicon,
10 respectively, and $x > 0$ and $y > 0$, and a maximum temperature in a production process is
expressed as T [°C].

18. The method for producing a semiconductor device according to claim 17, wherein

the gate electrode is made of a material containing silicon, and

15 $y/(x+y) \leq 0.30.$

19. The method for producing a semiconductor device according to claim 7, wherein

the gate electrode is a metal gate electrode,

the method comprising the step of performing a heat treatment with respect to the
20 substrate after the step of forming a conductive film.

20. A method for producing a semiconductor device comprising the steps of:

forming a high dielectric constant film containing a metal, oxygen and hydrogen on
a substrate;

25 performing a heat treatment with respect to the high dielectric constant film to
diffuse silicon from the side of the substrate into the high dielectric constant film, thereby
forming a silicon-containing high dielectric constant film; and

forming a conductive film for serving as a gate electrode on the silicon-containing high dielectric constant film.

21. The method for producing a semiconductor device according to claim 20, wherein the metal is hafnium or zirconium.

22. The method for producing a semiconductor device according to claim 20, comprising forming an insulating film containing silicon, nitrogen and hydrogen on the substrate before the step of forming the high dielectric constant film; and

wherein the step of performing a heat treatment with respect to the high dielectric constant film comprises diffusing silicon contained in the insulating film into the high dielectric constant film, and forming a lower barrier film by diffusing the metal contained in the high dielectric constant film into the insulating film.

23. The method for producing a semiconductor device according to claim 20, wherein the step of forming the high dielectric constant film comprises forming the high dielectric constant film by CVD employing a source precursor containing the metal and hydrogen.

24. The method for producing a semiconductor device according to claim 20, wherein the step of forming the high dielectric constant film comprises forming the high dielectric constant film by CVD employing a source precursor containing the metal and a source gas containing hydrogen.

25. The method for producing a semiconductor device according to claim 20, wherein the step of forming the high dielectric constant film comprises forming the high dielectric constant film by PVD employing a target containing the metal in an atmosphere

containing hydrogen.

26. The method for producing a semiconductor device according to claim 20, comprising the step of forming an upper barrier by nitriding a surface of the silicon-containing high dielectric constant film between the step of performing a heat treatment with respect to the high dielectric constant film and the step of forming a conductive film.

27. The method for producing a semiconductor device according to claim 20, comprising the step of forming an upper barrier by nitriding a surface of the high dielectric constant film between the step of forming a high dielectric constant film and the step of performing a heat treatment with respect to the high dielectric constant film.

28. The method for producing a semiconductor device according to claim 20, wherein a temperature for the heat treatment in the step of performing the heat treatment with respect to the high dielectric constant film is 600°C or more and 850°C or less.

29. The method for producing a semiconductor device according to claim 20, wherein
$$T \leq 6.69 \cdot y/(x+y) + 749.4,$$
when a composition of the silicon-containing high dielectric constant film is expressed as M_xSi_yO , where M, O and Si represent the metal, oxygen and silicon, respectively, and $x > 0$ and $y > 0$, and a maximum temperature in a production process is expressed as T [°C].

30. The method for producing a semiconductor device according to claim 29, wherein the gate electrode is made of a material containing silicon, and
$$y/(x+y) \leq 0.30.$$

31. The method for producing a semiconductor device according to claim 20, wherein
the gate electrode is a metal gate electrode, and
the method comprising the step of performing a heat treatment with respect to the
substrate after the step of forming a conductive film.

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